LIFE EXTENSION IN HARD DISK DRIVES THROUGH VIRBRATION AND THERMAL DAMPENING USING POLYMER SPRINGS

DESCRIPTION

[Para 1] The present application claims priority under 35 USC §119(e) to US Provisional Application Serial No. 60/554,364 entitled HARD DRIVE HAVEN and filed on March 19, 2004, which is hereby incorporated by reference for all purposes.

[Para 2] During operation, the HDDs generate create vibration as they rotate. By definition, a hard drive system will undergo *rotational vibration* when an oscillating moment is applied. When a hard disk drive is idle, the oscillation can be caused by friction in the spindle bearings or by rotational imbalance of the platter(s). When the drive is under read/write or seek conditions, inertia forces from activity of the actuator arm can cause rotational vibration (RV) is characterized by **rad/s,** which is the rotational analog of linear acceleration **m/s2** or **g**. When HDDs are packaged in close proximity they can, and most often will, propagate RV from one drive to another degrading drive performance. The vibration can become excessive, particularly when adjacent HDDs are operated simultaneously. Moreover, as HDD technology progresses to faster rotational speeds and cost-reduction architectures, the vibration problems are exacerbated.

[Para 3] In addition to the drive-to-drive induced vibration, there is also the real possibility of vibration being induced by the environment in which the drives are located. As an example of this would be in a data closet, where network storage equipment is maintained, there could be a number of external sources that can induce vibration. An air conditioner in any relatively near location would be a good example.

[Para 4] Vibration can also come in the form of acoustic vibration or the HDDs can produce disturbing acoustic noise, particularly for the consumer product applications. As personal computer become more prevalent in the home and HDDs are being used for audio/video and entertainment applications, acoustic noise emissions are becoming important to consumers. Another factor in determine performance is acoustic noise by the HDD. For example, research has found that the leading question by consumers with respect to hard drives was *"How loud will this drive be in my system?"* The acoustic noise comes from two noise generally comes from two sources.

[Para 5] Excessive vibration may lead to decreased HDD performance such as recoverable and non-recoverable write inhibits, increased seek times, and increased read and write access times. Excessive vibration or shock may also cause premature HDD failures that are not repairable. Examples include mechanically-damaged platters and read/write heads, mechanical wear on moving HDD components, and data error defects that cannot be corrected through the use of software tools. Also many HDDs in a confined space results in a substantial amount of heat generation. This heat must be dissipated in order to avoid over heating the HDDs and causing shortened product life.

[Para 6] Currently, there is a void in the market as far as a complete solution that addresses vibration, thermal, and all other physical issues (mass, structure...) for hard drives. The proliferation of hard drives is growing rapidly. The typical CAGR (compound annual growth rate) for the various segments of the Storage Area Network (SAN) and Network Attached Storage (NAS) arenas are growing at a ~67% (typical). An increase in HDD performance will have a significant effect when considering the tremendous numbers of drives in operation.

[Para 7] Much of the HDD industry continues to ignore the threat of damaging vibration as failure rates become exceedingly high and grasp at ineffective solutions. The nature of almost all problems is the need to resolve opposing constraints. The constraints invariably pull any of the possible solutions to a problem in different directions. Almost without fail, all solutions find that in improving one problem constraint that they diminish the solution from the aspect of one, or more, of the other imposed constraints. The position of making trade-offs and finding a "balance" of the capabilities needed to satisfy the need(s). An example of a potential solution that attempts to partially address the above-listed problems is included in US Patent Publication No. 2003/0222550 (US Application Serial No;. 10/417,111 filed April 17, 2003), invented by Boswell et. al and currently assigned to Xyratex Ltd. of Great Britain, which is hereby incorporated by reference for all purposes. However, the Boswell teachings do not fully address many of the relevant issues discussed above.

[Para 8] In view of the foregoing disadvantages in the known types of hard drive storage systems, the present invention provides a new solution wherein the same can be utilized for the storage of multiple hard drives.

[Para 9] The present invention includes a packaging solution for hard disk drives that is a comprehensive embodiment promoting long term, reliable hard disk drive performance. The present invention not only completely addresses hard disk drive packaging requirements, but in particular embodiments provides a highly cost effective solution in the packaging and manufacture of hard disk drives in multiple markets. The solution provided by particular embodiments of the invention can be implemented for any number of hard drives, individually, or in any multi-disk configuration. The

device embodying a preferred embodiment of the present invention for use in the hard disk drive market, will be referred to as the Hard Drive Haven™ (also referred to as HDH™) in the present application. Although many solutions look to improve the drives performance, HDH™ instead offers to provide an environment that the drive will not need to improve, as the threats will be so greatly diminished.

[Para 10] The present invention is generally applicable to hard disk drives in its preferred embodiments and more specifically it relates to an all encompassing solution for the storage of hard drives in a single or multi-hard drive environment. Although the invention primary envisioned for use with hard disk drives, the inventive concepts disclosed herein extend into many other industrial, commercial and personal applications in other alternate embodiments, without departing from the spirit and scope of the invention.

[Para 11] The present invention takes advantage of the properties of carefully selected dampening materials by considering the polymer science, making the Hard Drive Haven™ an excellent HDD environment. The Hard Drive Haven™ provides an optimum HDD packaging for long term and reliable operation. As can be appreciated by those skilled in the art, the proper composition and configuration of materials used in the Hard Drive Haven™ is determined through analysis and resolution of vibration and resultant noise in the hard disk drives. Such analysis requires advanced techniques in modeling, analysis and testing, as well as consideration in the relevant materials technologies.

[Para 12] In a first and primary embodiment, the HDH™ is made of polymer which serves as a dampening device to minimize vibration, but also provides a thermal advantage, because it is a reduced-space or "footprint" solution, which also leaves as more open air maximizing air flow volume for cooling the HDDs.

[Para 13] The hard disk drives (HDD) are mounted in various embodiments of the Hard Drive Haven™ in a wide range of devices and physical locations from personal computers to Storage Area Networks (SAN) to Network Attached Storage (NAS) appliances, such as Redundant Array of Inexpensive Disks (RAID) arrays, Just a Box of Disks (JBODs), servers and a host of bulk data memory devices. HDD bay or chassis located within a system enclosure in a personal computer, in a JBOD, or any other location where the HDH™ could be easily installed.

[Para 14] The present invention addresses many of the constraints involved in the packaging of HDDs, while simultaneously improving many performance indicators. The Haven offers a complete benign environment for a hard drive.

[Para 15] The following list articulates a number of attributes, *inter alia,* that describe some of the feature and advantages of certain embodiment of the invention as embodied in the Hard Drive Haven™. All of the attributes listed apply to the performance, handling, distribution and long term reliability of hard drives. However,

the list would be a very appealing list to many other applications for which the HDH™ could be easily adapted.

[Para 16] The invention provides for a low cost of manufacturing and low product cost (initial tooling cost has been calculated to be a one day payback for a $50,000 tool based on extreme market demand and the piece part cost would be exceptionally low as compared to most existing alternatives – injection molding process is most likely, but not the only possibility).

[Para 17] Minimal part count, light weight and application flexible

[Para 18] Thermal Environment - minimal structure allowing maximum cross section for cooling air flow

[Para 19] Vibration & Shock Isolation and Damping

[Para 20] Minimal Packaging Complexity – with maximum hard drive density

[Para 21] Acoustic Noise Reduction

[Para 22] High Mechanical Integrity

[Para 23] Structural Stability and Efficiency

[Para 24] Minimal Mass (Mass Efficiency) –important in that HDDs are massive and the loads on data-com equipment racks will go up sharply with densely packaged hard drives, particularly if the packaging weight is not minimized.

[Para 25] Reliable Interconnect (Hot Plug) - Intelligent use of forces to create simple, highly reliable connector alignment, with no mechanical piece parts

[Para 26] Improvements in electrostatic discharge

[Para 27] Ground isolation, advance pins on hot plug handle the discharge of any discharge.

[Para 28] Simple field replacement ability- could even ship hard drives in OEM packaging for direct installation in the SAN and NAS.

[Para 29] Simple Field Serviceability – Drive Level Replacement (with no additional replacement components)

[Para 30] Designed for minimal field service

[Para 31] The industrial design is facilitated by existing faceplate design and snap fit features for assembly into the HDH™.

[Para 32] The present invention provides the disk drive industry with an improved hard drive storage system that has many of the advantages of the HDH™ mentioned above but also include:

[Para 33] allows the airflow passages are optimized.

[Para 34] provides an excellent thermal environment.

[Para 35] reduces vibration (external and drive to drive, RV), shock, and acoustic noise.

[Para 36] allows ease of distribution and replacement for hard drives in the field (shipped in original packaging).

[Para 37] structurally sound and minimizes mass.

[Para 38] provides electrostatic discharge and electrical grounding isolation for the HDDs.

[Para 39] allows for highly reliable interconnect without the need for any mechanical alignment features.

[Para 40] low cost overall Solution for the packaging of hard drives.

[Para 41] completely snap fit assemble.

[Para 42] manage polymers in a vibration damping environment that has exceptional durability. This by using a variety of beam elements that work in unison to off load and not allow the over stressing of any other beams in the structure.

[Para 43] provide a common platform for mounting of hard drives to provide a predictable, benign and fully optimized solution to promote long term reliable hard drive performance.

[Para 44] standardize this platform in order to better compile consistent data of hard drive performance to continue to drive the technology to greater levels of capacity and performance.

[Para 45] provide the first complete solution for hard drives , from the manufacturer to end of life of each individual hard drive.

[Para 46] The features and attendant advantages of the present invention will become fully appreciated as the same becomes better understood when considered in conjunction with the accompanying drawings, in which like reference characters designate the same or similar parts throughout the several views, and wherein. Please note that the drawings shown here are of the least complex beam structures, as this demonstrates the principle most clearly. There are a great range of beam cross sections and combinations that are under analysis and being shaped to optimize the Haven's performance. In later pages there will be drawings of a number of beam shapes and combinations rendered to demonstrate a small sample of the wide range of form factors that could and will be used to satisfy the needs of hard drives and other devices needing an environmental Haven.

[Para 47] FIG. 1 is a perspective view of the present invention;

[Para 48] FIG. 2 is a front of the present invention showing all of the components;

[Para 49] FIG. 3 is a side view of the present invention;

[Para 50] FIG. 4 is a perspective view of the faceplate interfaces to the drive and the present invention;

[Para 51] FIG. 5 is a partially exploded view of the present invention;

[Para 52] FIG. 6 is a chart that illustrates the relationship to temperature and disk drive performance;

[Para 53] FIG. 7A is a representative example of the pre-stressed or load deflected compression polymer member.

[Para 54] FIG. 7B shows the results of 7A.

[Para 55] FIG. 8 illustrates the details present of the materials used in the faceplate for present invention and their operation;

[Para 56] FIG. 9 illustrates shielding effectiveness;

[Para 57] FIG. 10 illustrates pressure drop in the present invention;

[Para 58] FIG. 11 shows an overview of the present invention it may be implemented.

[Para 59] Turning now descriptively to the drawings, in which like reference characters generally denote similar elements throughout the several views, the attached figures illustrate a hard drive mounting structure which is comprised of a polymer and which will be discussed more fully below.

[Para 60] In the following disclosure, the preferred embodiment of the present invention will be referred to by one of its trade names the "Hard Drive Haven"™. The Hard Drive Haven™ has a vibration dampening system that will damp vibration to and from other co-located hard drives and/or from external excitations from the local environment. The vibration that is created from other hard drives is referred to as RV, which stands for **Rotational Vibration**. Hard drive have rotating platters and this rotational energy can be transmitted from one hard drive to another and cause the receiving drive to experience a drop in performance. The hard drive Haven will utilize a very carefully structured series of beams that will combine in damping out vibration and acoustic noise over a wide range of frequencies and energy levels. The vibration dampening features will be molded from the structure that also serve as the support structure for the hard drives and as a stiffening system for the computer, server, storage array, digital recorder, desktop hard drive enclosure and many other possible applications. The focus herein is on hard drives but the application of this solution is extendable to any number of devices that are benefited be having vibration, shock and acoustic vibration damped from their operating environment.

[Para 61] The present invention takes advantage of the fact that many Polymer composites have been found to have excellent damping properties that can be used to help control any unwanted vibrations produced by external dynamic loading. Moreover,

the great flexibility available in composite structures through changing both materials and designs can be used to alter damping and resonance properties in desirable ways. See enclosed documents regarding these composites.

[Para 62] Examples of appropriate polymers for computer applications include Delrin, Celanese, and Celstran. There are many polymers that offer the properties that will be required for the hard drive haven. Ultem, Valox and Noryl are three such polymers, as examples. Careful analysis, including finite element modeling will be necessary to ensure that the polymer(s) used can withstand the test of time and not yield as a result of creep and/or fatigue. In order to facilitate implementation of many possible embodiments of the invention, references relating to the properties of polymers are incorporated herein. These publications include *The Handbook of Materials Science* (McGraw-Hill), and Additionally, the series by Bill Fry and published by the Society of Manufacturing Engineers *Speaking of Plastics Manufacturing (1999), Working with Acrylic, Working with Vinyl, etc.* may also be useful in determining the relevant properties of plastics and polymers in the manufacturing process of the present invention and is incorporated by reference. However, sample materials included in table A below are specifically incorporated by reference.

[Para 63] The illustrations included herein reflect only a few of the possible beam structures that can be employed by the Hard Drive Haven™. With no beam beings tresses and or strained past the limits of the material used ensuring that the HDH™ prevails for the life of the product. The inventive suspension system holds the hard drive in a slot in the housing with the polymer springs. The polymer springs isolate the hard drive from the side panels and dampens the vibration produced by the hard drive itself as well as the vibrations transmitted through the sidewalls of the hard drive bay housing. The springs provide constraint and damping in an omni-directional manner, negating the adverse effects of vibration and acoustic noise from any conceivable source within the operating environment.

[Para 64] Referring to FIG. 1, a primary embodiment of the invention is illustrated and includes a side panel 101 of a housing that incorporates an embodiment of the inventive hard drive suspension system. A second side panel is mounted in parallel 501 (as also shown in FIG. 5) with the illustrated panel so that both sides of the hard drives are in contact with the polymer springs. In the illustrated embodiment (which is only one configuration of many possible, single drive up to as many as required by the application), there are slots 106 for four hard drives which are separated by dividers 105. The inventive suspension system comprises a polymer compression member which in this embodiment is an arched beam 102 that is incorporated into each of the dividers 105, contact the hard drives on the upper and lower surface of the devices. In addition there are compressive members 103 that contact the hard drives on the sides of the devices and compress as the drives are inserted into the hard drive haven. The beams are therefore in compression in both the vertical 102 and horizontal 103 axis of the hard drives and due to the nature of the forces that ill be encountered and the

nature of the polymers will act as omni-directional; reactions to all forces. The actual hard drive haven will employ beams of similar conceptual design, but may be very different in form factor as a result of detailed finite analysis. The greatest likelihood is that multiple beams of varying stiffness will be employed to react the multiplicity of stimuli the hard drives will encounter in operation. The diagrams enclosed are therefore intended to represent the concept and do so from a fundamental conceptual point of view. The multi stiffness beams will be designed to work in unison with each other being recruited as the load becomes more aggressive , for example in shock, but not allow the load to be too great on lesser strength beams before a stiffer load bearing beam is recruited.

[Para 65] In a particular embodiment, the inventive suspension system also has springs or spring-like structures that engage the sides of the hard drive. These springs are similar to the springs in the dividers as described above, but are mounted in the center of the slots of the side panel. The side springs are made of a flexible polymer and have an arched structure that is attached at the ends of the beam to the side panel.

[Para 66] The Hard Drive Haven™ also delivers a structurally efficient solution because of the strength to weight ratio of the materials chosen for use in the present invention. The molded plastics that are implemented in the present invention is greater than cold rolled steel, which is almost always used in such applications. For example, the mass of polymer is generally on the order of ~ 1/8 that of cold rolled steel. Increasing the strength to weight ratio is very important in implementing particular embodiments of the present invention, as the mass of the systems including multiple hard drives is increasing, and the "floor loading" of data centers will not be able to accommodate bays that are filled with such mass dense packaging.

[Para 67] In particular embodiments of the invention, the Hard Drive Haven™ also provides an assembly-conscious design that anticipates significantly reducing the effort required for manufacture. The Hard Drive Haven™ will "snap fit" into a sheet metal chassis. Reference 107 is a tongue (3 along the bottom of the bottom of the HDH and one at top center) that will fit into a slot in the sheet metal chassis (in the case where this is the final implementation). The top springs 102 will maintain the HDH in compression between the upper and lower sheet metal housing. The HDH also will include integral faceplates that provide a single snap-fit for the drive to the faceplate 403 and a single snap fit for the hard drive/faceplate combination in to the HDH 104/404. Therefore for applications (Enterprise or example) that HDH™ requires only three snap fit assembly steps for full HDH™, hard Drive and faceplate assembly. With the use of metalized plastics that Electro-magnetic aspects of an enterprise solution can also be accommodated. It will often be necessary in enterprise applications to accommodate light pipes to provide optical feedback that the hard drives are operating correctly. These light pipes can easily be accommodated in the HDH side walls.

[Para 68] FIG. 5 shows an example assembly of eight hard drives. The hard drives can be mounted right side up or upside down (as shown) 503. System architecture will dictate the most prudent choice in this case. The HDH can package the drives in very close proximity, but provide the necessary cooling air, structural integrity, vibration/shock/acoustic damping, ease of assembly, and a multitude of other benefits that are all delivered at an exceptionally low cost.

[Para 69] The preferred embodiment of the invention requires virtually no packaging, accepts the drive into the shelf with nothing required but a faceplate. Such a packaging system leaves all of the cross-sectional area between the drives free for delivering cooling air. This is important not only for the proper operation of the drives, but it is also very important for other system components, downstream of the drives, these components, often containing processors, can reject a great deal of heat. It is critical that drives be well cooled, and that the portion of system they reside in is not so densely packaged so ass to slow the flow in the entire system. The HDH makes sure that as much of the critical airflow volume is available for the system components.

[Para 70] The inventive suspension system of the present invention has numerous cutouts in the side panels. These "holes" are generally located next to the tops and bottoms of the hard drives allowing air to more freely flow over the upper and lower surfaces. The increased air flow, allows the inventive system to more easily cool the stacked hard drives through convection heat transfer.

[Para 71] The thermal environment – it is a widely held opinion that the performance and length of time in which a hard drive will continue to function is inversely proportional to the temperature of the environment in which it operates. The actual degree to which the temperature is elevated is where the debate lies, but it is clear that the lower temperatures are better. With that said, one needs to understand the reality of where the hard drives will be deployed to realize that there in no good way to be certain of the ambient temperature that will be encountered and that this will be variable depending on what the final implementation is. Therefore, the drives will have to operate under a number of different environmental ambient temperature states. Since you cannot guarantee the temperature of the cooling air, then it is critical to guarantee that there is enough air to effectively remove the heat that the drive itself generates. I now include the first graphic to assist in the description of the intellectual property described herein. Please note that the majority of the hard drive market is moving rapidly toward very dense packaging of hard drives to provide low cost data storage solutions. The increasing packaging density and the ever increasing capacity of the hard drive, making the thermal environment ever more aggressive for the hard drives and incrementally reducing the life expectancy of the hard drives. The need to get whatever little air possible to the drives and efficiently removing whatever heat possible is more critical that ever before. As shown below, the present invention addresses the thermal issues as well as many other aspects of hard drive packaging.

[Para 72] Disk drives are complex electro-mechanical devices that can suffer performance degradation or failures due to a single event or a combination of events occurring over time. Environmental conditions that affect drive reliability include ambient temperature, cooling air flow rate, voltage, duty cycle, shock/vibration, and relative humidity. Fortunately, it is possible to predict certain types of failures by measuring environmental conditions. One of the worst enemies of hard disk drives is heat. Within a drive, the reliability of both the electronics and the mechanics (such as the spindle motor and actuator bearings) degrades as temperature rises. Running any disk drive at extreme temperatures for long periods of time is detrimental and can eventually lead to permanent data loss.

[Para 73] The following paragraph, as illustrated by FIG. 6, paragraph comes from a white paper entitled *Hitachi's Drive Temperature Indicator Processor (Drive-TIP) helps ensure high drive reliability"* by Gary Herbst, which is hereby incorporated by reference. To look at an example of the relationship between temperature and hard drive (MTBF=Mean Time Before Failure; HDD = Hard Disk Drive). FIG. 6 shows the dramatic effect that temperature has on the overall reliability of a hard disk drive. Derivations from a nominal operating temperature (assumed to be maintained over the life of a drive) can result in a derivation from the nominal failure rate. As the temperature exceeds the recommended level, the failure rate increases two to three percent for every one degree rise above it. For example, a hard disk drive running for an extended period of time at five degrees above the recommended temperature can experience an increase in failure rate of 10 to 15 percent. Likewise, operating a drive below the recommended temperature can extend drive life.

[Para 74] Normal mounting systems rigidly attach the hard drive to the slots or bays of a storage unit with screws and sheet metal slot components that physically contact the hard drive. Because of this rigid connection outside vibration is transmitted to the drive and the vibrations produced by the hard drive are transmitted to other hard drives in the housing exacerbating the vibration problem. In contrast to a rigid connection, the inventive hard drive suspension system isolates the hard drive from the frame with polymer springs which effectively dampen the transmitted vibrations. The polymer springs allow the hard drive to move in all three axes.

[Para 75] In addition to vertical movement, the hard drive may also move from side to side or forward and backward in the slot. This freedom of movement results in reduced vibration transmitted to the hard drive from external sources. In addition to the mechanical spring properties, the polymer also has vibration absorption characteristics. In a normal spring, the physical energy resulting from compression is stored and released as the spring expands. In a preferred embodiment, the polymer springs are made of a material that absorbs some of the compression force and converts this energy into a different form. The energy may be converted into heat energy or alternatively, with a pizo-electric mechanism the physical energy can be converted into electrical energy.

[Para 76] Polymers are effective in their response to a variety of vibration related issues, including: absorption of airborne sound; blocking airborne sound; damping, and vibration isolation. The HDH™ will employ polymers, composites and other appropriate materials in addressing all these issues, in a manner that is cost effective and delivers all requisite HDD packaging needs.

[Para 77] Referring now to FIGS. 7A and B, a load deflection treatment and stiffening effect is shown. The stiffening effect results from the fact that the thin wall is stretched into tension as the plate deflects at P. The load deflection shown in FIG. 7A, illustrates this phenomenon with the results shown in FIG. 7B. For effective vibration control, it is often desirable to have a response that provides greater stiffness as the load increases. The behavior of membrane or shell stiffness, in polymers, provides this behavior without incremental cost. Simple it is a function of the geometry. With proper material selection, the cross section can be matched to the expected loading of the application. Diaphragm stiffening is a nonlinear increase in stiffness resulting from a change in curvature of a part. This effect is particularly pronounced when fixed boundary conditions are used.

[Para 78] There are a variety of different materials that can be utilized for the stiffening effect, depending on the device(s) form factors, level of damping required and the magnitude of the input forcing function. Diaphragm stiffening is a nonlinear increase in stiffness resulting from a change in curvature of a part. This effect is particularly pronounced when fixed boundary conditions are used.

[Para 79] The table below provides information on examples of polymers that might be employed for the Hard Drive Haven™, in which the relevant technical details are incorporated by reference, demonstrating the properties that are required to deliver the performance necessary for the life of the systems in which the HDH™ will be employed. Data sheets of polymers that may be applicable to this invention, which are hereby incorporated by reference, and include some of the materials described below.

Material /Tradename	Manufacturer/Distrib.	Notes and technical materials, incorporated by reference
Delrin	Dupont	
Hytrel	Dupont	Thermoplastic and elastomer
Zytel	Dupont	Glass-reinforced
Noryl	GE	website
Ultem	GE	"
Valox	GE	"
Premiere Chomerics EMI	Parker-Hannefin	Incorporated by reference. Used for faceplate and

		possibly for the springs
Capron	BASF	

[Para 80] Simplified, lower mass and higher strength structures, reduced packaging complexity, with increased reliability, serviceability, and ease of assemble are all important factors to consider. Ease of integration of industrial design features, ease of shipping replacements (could use the HDH™ or if not send drives in their original packaging and pop on a face plate at the site and slide into the HDH™).

[Para 81] It is to be understood that the invention is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of the description and should not be regarded as limiting.

[Para 82] The present invention also benefits from the reconfiguration of the faceplate to include. Referring now to FIG. 8, a diagram of a sample material used in the present invention, as shown in FIG. 4, in the face plate, is shown. The D (open) cell dimension) and C (pitch or valley o valley) dimensions, showing the amount of Open Area (OA) in a sample faceplate, indicating the reduction in mass as well as the increase in air flow.

[Para 83] Referring now to FIGS. 9 and 10, various properties are shown for shielding effectiveness and pressure drop respectively. FIG. 11 shows an overall view of an alternate embodiment of the present invention.

[Para 84] While the invention has been shown or described in only some of its forms, it should be apparent to those skilled in the art that it is not so limited, but is susceptible to various changes without departing from the cope of the invention. For example, the dampening materials may be formed from a thin film, sheet, molded or a combination thereof, and may be placed at a variety of interfaces to further reduce vibration and shock.